~~Circuit Arrangement for the Dynamic Control of~~
Ceramic Solid-State Actuators

Description

The invention relates to a circuit arrangement for the dynamic
control of ceramic solid-state actuators, such as for example,
piezotranslators with energy recovery by means of magnetic
intermediate stores according to the preamble of Claim 1 as
~~well as a control-loop for operating a piezotranslator.~~

Piezotranslators are electrically controllable actuators whose
functions can be attributed to the piezoelectric effect.
Active sensors, so-called actuators, can perform the most
delicate positioning movements with high accuracy from the
subnanometer up to the millimetre range.

Under electrical aspects, a piezotranslator represents a
capacitor whose charge has a proportional relationship to its
expansion. Consequently, piezotranslators take up energy dur-
ing the expansion process only. The expansion is maintained
without further energy supply. Due to the high capacitance of
the piezotranslators, however, a high output power of the
driver circuit is required in the case of fast positional
changes as they occur under dynamic operation conditions. The
associated control electronics must therefore have special
properties for each application case and has to be optimised
in order to ensure the successful employment of a piezotrans-
lator.

In control processes for the dynamic piezocontrol in which the
actuating element must follow up fast changes of a reference
variable, it is desired that the amplitude of the movement
characteristic agrees with the input signal as close as poss-

ible. However, such a linear transfer behaviour cannot be ensured for frequencies up to any magnitude, but is limited, on the one hand, by the resonance frequency of the translator or the entire actuating system, respectively, and by the out-

5   put power of the amplifier, on the other hand.

Due to the hysteresis phenomena of a piezotranslator the absolute expansion of the actuating element can be determined only inaccurately via the applied amplified input voltage of

10   the amplifier. The resulting expansion has an inherent error of up to 10%, both with respect to its absolute value and to its relative movements. In order to eliminate this error, it is known to provide closed control loops, i.e. a measuring system for the expansion and control electronics which control

15   the operating voltage in accordance with a comparison of the reference variable and the actual value. Closed positioning control loops are therefore provided with external probes in order to be able to determine the position.

20   Due to the fact that piezotranslators can electrically be described as capacitors, as mentioned above, onto which electric charges must either be applied or from which said charges must be withdrawn for the purpose of a length vari-ation, which for example can be realised by means of a switch,

25   charging or discharging between the piezotranslator, on the one hand, and the charging current circuit, on the other hand, will inevitably result in power losses, if this is done via controllable variable resistors, e.g. transistors.

30   From the final report of the joint project "Entwicklung lei-stungsoptimierter, hybrider Hydraulikkomponenten auf der Basis piezoelektrischer Aktuatoren" (Development of Power-Optimised Hybrid Hydraulic Components on the Basis of Piezoelectric Actuators) of the Institut für Fertigungstechnik und spanende

35   Werkzeugmaschinen (Institute of Manufacturing Engineering and

Metal Cutting Machine Tools), Hanover, Germany, November 1996, it is known to design digital control amplifiers for driving piezoelectric actuators, which are provided with a controlled energy recovery capacity. The known final stage preferably includes inductively coupled coils in order to increase the efficiency of the energy recovery.

In the known circuit arrangement two separate magnetic intermediate energy stores are provided, with the energy stores being switched by a controller in a clocked manner, in order to achieve a predetermined output voltage curve of the control circuit. At the piezotranslator a voltage-dependent non-linear charging of the capacitance will result, with the available current decreasing upon reaching the supply voltage. Due to the circuit arrangement as two separate blocking transformers, only one direction each of the output current can be driven.

In order to obtain a desired linear voltage increase at the piezotranslator, the storage volume of each store must be designed extremely large in the state of the art. The reason of this is that the blocking transformer must be dimensioned according to the smallest voltage increase ΔU at the range limits of the operating voltage. In the middle output range, however, the available storage volume cannot be utilised so that a correspondingly implemented output amplifier does not operate efficiently.

With respect to the control of piezotranslators in actual applications, the actual momentary value of the output voltage supplied to the piezotranslator is determined by means of a control loop. This is to compensate for existing deficiencies of the control circuit or the final stage, respectively, such as its non-linearity, temperature drift, and frequency dependence, as well as any undesired behaviour of the connected

piezotranslator because of the already mentioned voltage
hysteresis.

In this context, it has been known to apply part of the piezo
5 output voltage as the actual value to the input of an error
amplifier, or to use an exact physical measuring system which
yields an output voltage as the actual value. The desired
reference variable is supplied to the input of the error
amplifier, with the output of the amplifier being connected to
10 the control circuit itself.

The above described controller concept achieves satisfactory
results with arrangements without energy recovery, which are
mostly equipped with a conventional loss-inherent final stage
15 of the type of controlled series resistors. However, problems
occur with a corresponding use in energy recovering control
circuits. The reason for this is the considerable inductances
which are responsible for the desired energy recovery and
which are connected in series to the piezotranslator. Together
20 with the piezotranslator which represents a capacitor these
form a high-quality series or resonance circuit. Depending on
the type or size of the translator and employed inductor, its
resonance frequency is mostly within the frequency band in the
range from 1 to 5 kHz, which is of interest for the amplifier
25 operation. The series resonance circuit in turn causes a high
increase of the amplification in the resonance range, together
with an undesired phase shift in the working band of the con-
trol loop approaching the critical 180° limit, which affects
the compensation. From this, an undesired post-pulse oscilla-
30 tion or self-oscillation results. The desired flat amplitude
characteristic of the overall system up to the upper working
frequency range is therefore no longer achievable.

Therefore, it is the object of the invention to provide a
35 circuit arrangement for the dynamic control of piezotrans-

lators with energy recovery as well as an improved control loop for the operation of piezotranslators, which allow the almost linear charging of the piezotranslator over the entire voltage range and at the same time the optimisation of the energy recovery with a small installation size of the implemented circuit. Simultaneously, energy storing elements such as capacitors or accumulators must be able to be operated at a maximum piezotranslator supply voltage so that the return currents can be maintained correspondingly low. With respect to the control loop, it is essential to prevent points of resonance in the working and transfer range so that any self-oscillation can effectively be avoided.

~~The object of the invention is solved by means of a subject~~ matter as it is defined in the valid Claim 1 as well as in Claims 4 and 5 as far as the closed loop control is concerned. The remaining dependent claims represent at least suitable ~~embodiments or developments of the invention.~~

The basic idea of the invention is to form the control circuit for the dynamic operation of piezotranslators as a half-bridge circuit with a single series coil as an intermediate energy store. In this case, the maximum available current for charging and discharging the piezotranslator is identical with the maximum current of the series coil. Such a limitation occurs unchanged and at a constant limit current over the entire range of the piezo output voltage. For the capacitance of the piezotranslator the constant limit current causes a constant voltage increase so that the storage capacity of the intermediate energy store is uniformly and fully utilised over the entire working range. The installation size can be reduced due to the use of a single series coil, with the indirect consequence of a cost reduction.

According to the invention, a direct-current superimposed single coil is employed as an intermediate energy store, with the coil to be considered as a forward converter under the aspect of its effect. The coil direct current flows during the entire activation period and is modulated by a high-frequency alternating current with a relatively small amplitude at the working cycle of the half-bridges, i.e. of the employed switches, at a frequency of essentially 100 kHz.

By means of the inventive arrangement of a single inductive magnetic intermediate store in the secondary circuit which is connected in series with the piezotranslator and with the secondary circuit being designed as a half-bridge, it is possible to significantly increase the efficiency of the power final stage formed in this manner. Due to the fact that there is no internal electrical isolation, the losses can be reduced further. Also otherwise present drawbacks due to voltage losses at the energy recovery diodes do no longer occur in a comparable magnitude. A transfer of the entire energy in the piezotranslator in each modulation wave to the primary side and back again as this is the case in the state of the art is no longer necessary.

Due to the fact that the only energy store is located on the secondary side and is subjected to the high piezo voltage which, depending on the translator type, is between 100 and 1200 V, the currents during the energy recovery can be kept low. With respect to circuit engineering, the only intermediate store can be arranged in a spatially close relationship with the piezotranslator so that electromagnetic radiated noise can be reduced to a minimum. A still better electromagnetic compatibility results from the effective modulation current which is superimposed by only a low high-frequency alternating current according to the external cycling of the half-bridges. By a corresponding dimensioning of the inductive

intermediate store, the superimposed alternating current is in the order of essentially 10% of the modulation current so that the residual ripple will be greatly reduced.

5   Another basic idea of the invention is that when using MOSFETs as switches, the negative effects of existing internal inverse diodes can be avoided. For this purpose, the invention proposes to connect an external blocking diode in series with the clearance between open contacts and to bridge this series con-

10   nection by an oppositely poled commutating diode. This additional diode combination prevents the inverse operation of the MOS transistors by its internal inverse diode and allows a quasi external inverse operation by the commutating diode which is oppositely poled with respect to the external block-

15   ing diode.

The additional diodes have a shorter recovery time relative to the MOS transistor in order to considerably improve the operation of the modified half-bridge circuit under the aspect of

20   the switching frequency.

In the inventive control concept and according to another basic idea of the invention, a current sensor for determining a control voltage which is proportional to the output current

25   is arranged for controlling the piezotranslator. This current sensor is connected with the input of a first controller, with the second input of the first controller being applied to the output of a second controller at whose inputs a given reference variable corresponding to the physical position of the

30   piezotranslator and the reduced output voltage is applied.

Accordingly, the control concept consists of two nested, separate control loops, i.e. an inner and an outer control loop. The inner control loop encompasses the control circuit

35   proper, including a potentially critical point of resonance

which is formed by the magnetic energy stores which are provided there in any form and the capacitive load of the piezo-translator.

5 By means of the outer control loop it is possible to achieve the characteristic of the output voltage which is defined by the input signal, i.e. the reference variable, of the position and expected with an amplified amplitude at the amplifier output.

10 Due to the fact that the inner control loop has already eliminated the point of resonance and the associated additional phase shift in the working frequency range, the outer control loop can be optimised in a simple manner. As a whole, the
15 design of the circuit arrangement for controlling purposes offers an improved overall transfer behaviour. The amplitude characteristic is uniform over the entire frequency range, including the point of the critical LC circuit and drops without transition point. The phase characteristic has a phase
20 margin of at least 50° and is not critical, while it is possible to keep the time behaviour at the maximum system dynamics free from resonances and overshooting.

As explained above, the inner control loop operates by utilising a current proportional sensor signal, with a current
25 transformer being provided for this purpose. This current transformer can be realised by a simple series resistor in the return line of the load current or by a simple transformer circuit. The inner control loop thus enforces a current of a
30 predetermined magnitude at the output of the final stage or of the control circuit, respectively, which flows into the load and which can be controlled in its time characteristic by the specified reference variable. Any additional loads connected with the capacitive piezotranslator load, such as, for

example, a storage coil, have no influence on the common load
current and cannot cause resonance phenomena.

Due to the fact that the voltage which is normally building up
at the piezotranslator is defined by the integral of the
current, the now controlled current, however, no longer has a
point of resonance, it is possible to keep the piezovoltage,
too, free from resonances. The inductance of the intermediate
store, which is introduced for energy recovery, is no longer
detected by the control behaviour of the inner control loop as
a resonance-generating component and thus eliminated to the
outside.

In an embodiment of the invention, an additional positioning
control of the system is performed according to another basic
idea, in that a third controller is provided at the first in-
put of which the reference variable of the physical position
of the piezotranslator and at the second input of which a
physical actual value of the piezotranslator, which is detect-
ed via a sensor, is applied, with the output of the third con-
troller being connected with one of the inputs of the above
mentioned second controller.

The dynamic behaviour of the control system with inner and
outer control loop can be improved according to another basic
idea of the invention in that the second controller feeds back
the integral of the piezotranslator current instead of con-
trolling an output voltage which is proportional to the refer-
ence variable. This alternative feedback can be activated in a
frequency dependent manner.

In a preferred embodiment, the integration value is used at
frequencies of essentially > 10 Hz, and at frequencies of
< 10 Hz, the mentioned voltage feedback is performed.

The described advantage of the improved pilot control also has
a positive influence of those control loops in which an addi-
tional positioning control by means of a further controller is
dispensed with. These advantages are particularly effective at
5   the upper limit of the working frequency range where the loop
amplification must be reduced because of the operational sta-
bility and is therefore too low for an effective error com-
pensation.

10   The invention will be described in more detail by means of
embodiments as well as with reference to the figures in the
following.

In the figures:

15

Fig. 1   shows a circuit diagram of the circuit arrangement for
         the dynamic control of piezotranslators with energy
         recovery;
Fig. 2   shows a configuration of the MOSFET switch with an
20   external blocking diode and a commutating diode
         oppositely poled relative to same;
Fig. 3   shows a block diagram of the control system with an
         inner and an outer control loop comprising the
         optional possibility to adapt the outer control loop
25   to the integration value of the current;
Fig. 4   is an illustration of the control system with addi-
         tional positioning control;
Fig. 5   shows a block diagram for reducing the low frequency
         voltage noise; and
30   Fig. 6   shows a block diagram of a known fine control.

The circuit diagram of Fig. 1 shows a circuit arrangement for
the dynamic control of piezotranslators.

As can be seen, a single inductive intermediate store 1 is
connected in series with the piezotranslator 2. The illustrat-
ed secondary circuit shows a half-bridge arrangement, with
switches 3 and 4 being externally clocked with up to 100 kHz.
5   The switches 3 and 4 are bridged by energy recovery diodes 5
and 6. In the configuration of the switches 3 and 4 as MOSFETs
such diodes are integral members of this transistor family.

Voltage sources 7 and 8 for one half-bridge each are formed by
10   a switched-mode power supply known per se and comprise suit-
ably dimensioned storage capacities.

The coil direct current is superimposed by a low, high-fre-
quency direct current of small amplitude in the working cycle
15   of the half-bridges. The only energy store 1 reduces the
storage volume with respect to size and is operative both
during charging as well as discharging of the piezotrans-
lator's capacitance, i.e. over the entire operating time.

20   Compared to the known state of the art, the switching losses
according to the arrangement of the embodiment are consider-
ably lower. In order to obtain the intended linear output
voltage curve, the switches 3 and 4 are activated by a cor-
responding controller with high cycling or switching fre-
25   quency. The ratio of the closing times of switches 3 and 4
defines the working direction "charging" or "discharging". At
the piezotranslator 2 a linear charging of its capacitance in
the entire voltage range from 0 to UB max. is obtained.

30   With reference to Fig. 2, a preferred external wiring of a MOS
transistor or a MOSFET, respectively, to be used in the cir-
cuit arrangement according to Fig. 2, will be explained in
more detail.

For circuit engineering reasons, the mentioned switches 3 and 4 are employed in the final stages of the half-bridge according to Fig. 1. The connection of the intermediate store 1 is alternately made with the upper or lower supply voltage UB/2, respectively. Not more than one of the two switches 3; 4 is closed. Because of the configuration of the circuit arrangement, currents with both positive and negative sign occur at the switches 3 and 4. For example, a current flows through the closed switch at times which increases the average current in the intermediate store 1, which returns half a modulation period later as a so-called commutating current for the purpose of energy recovery.

In the case in which MOS transistors are used for the switches 3 and 4, the current return flow is not effected via the active element itself but via an internally provided parasitic inverse diode which is an inevitable element of the transistor. These inverse diodes need a considerable recovery time after having been temporarily subjected to a return current so that the MOS transistor can only be switched off with a long delay time. Therefore, said transistor, following an application of a return current, behaves like a complete short circuit over some time.

For operational reasons, long-term return currents flow in the described half-bridge for energy recovery, which originate from the energy store 1 and have been induced there, which pulsate with the modulation frequency and which, without external measures, continue for a multiple of the desired high clock frequency of 100 kHz. If such a current flows e.g. through the switch 3 inversely into the upper supply voltage UB/2, and if the switch 3 is then blocked for operational reasons and the switch 4 is closed, then a short circuit occurs in the clearance between open contacts 3, 4 during the recovery time of the switch 3 because the switch 3 cannot open

immediately. This will be repeated with the repetition or clock frequency, respectively, and is responsible for an essential portion of the losses within the circuit arrangement.

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As can be seen from Fig. 2, the MOS transistors are modified by a special external diode circuit. In the case at hand, an external blocking diode 10 is connected in series with the clearance between open contacts, with this series connection

10 being bridged by a commutating diode which is oppositely poled to the external blocking diode 10.

With such an arrangement it is possible to optimise the switching behaviour and to considerably reduce the power loss

15 of the circuit arrangement in its entirety.

The control concept according to Fig. 3 assumes an inner current control loop combined with an outer current control loop. The outer current control loop can be configured in such

20 a manner that the integral of the piezotranslator current is sensed and fed back instead of controlling an output voltage which is proportional to the reference variable. This alternative can be utilised in a frequency dependent manner, e.g. with f > 10 Hz, so that the dynamic behaviour of a correspond-

25 ing control loop for a piezotranslator is improved.

For controlling the piezotranslator 2, a current sensor 12 is provided in the secondary circuit according to Fig. 3, which generates a control voltage which is proportional to the out-

30 put current. Said current sensor 12 is connected with a first input of a first controller 13, with the second input of the first controller 13 being applied to the output of a second controller 14, if required, by connecting an amplifier and a filter 15 and 16 in between. At the input of the second con-

35 troller 14 a predetermined reference variable corresponding to

the physical position of the piezotranslator, on the one hand, and the fed back voltage of the secondary circuit or the integral of the piezotranslator current, on the other hand, are applied.

5

The final stage 18 which is controlled by the output of the first controller 13 via a filter 17 can correspond to the circuit arrangement for controlling according to Fig. 1, but can also be formed by two blocking transformers according to the state of the art. The inner control loop which is formed by the current sensor 12 and the first controller 13 comprises the final stage 18 including a potentially critical point of resonance which is generated by energy stores provided for energy recovery and the capacitive load of the piezotranslator 2. For the purpose of generating the characteristic of the output voltage which is specified by the reference variable of the position and expected at the amplifier output with an amplified amplitude, the outer control loop comprising the second controller 14 with voltage feed-back is provided.

In the case where the integral of the piezotranslator current is fed back, the outer control loop comprising the second controller 14 causes a correspondingly pre-distorted charac-teristic of the amplifier output voltage which, however, cor-responds to an essentially similar characteristic of the movement which is actually carried out by the piezotranslator 2 by the reference variable of the position without any hysteresis interference of the translator.

The embodiment according to fig. 4 shows an additional posi-tioning control, with reference being made to the explanations in conjunction with Fig. 3 with respect to the inner and outer control loop. The same elements are identified by identical reference numerals.

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A third controller 19 is provided for positioning control, at whose first input the reference variable of the physical position of the piezotranslator 2 and at whose second input a physical actual value sensed via a sensor 20 of the piezo-
5   translator 2 is applied. The output of the third controller 19 is connected with a corresponding input of the second controller 14, if required, by connecting an amplifier-filter combination 21 in between.

10   Switching and actuating the switches 3 and 4 with a clock frequency of approx. 100 kHz generates a residual ripple in the coil 1 and thus in the output current. Although this high-frequency ripple at the piezotranslator 2 will no longer result in a uniform physical movement, it nevertheless causes a
15   considerable mechanical stress, the extent of which depends on the type of ceramic, acting on this actuator element due to heavy partial oscillations.

According to a further embodiment a reduction of the current ripple which is superimposed on the output current can be
20   achieved as follows.

A series resonance circuit, formed by an inductance and a capacitor, is arranged in parallel with the piezotranslator. The two components make up a resonance circuit which is ad-
25   justed to the high clock frequency of 100 kHz. It diverts the high-frequency current to ground and thus past the piezotranslator 2. The advantage resulting therefrom can either be utilised for the piezotranslator 2 under the aspect of service
30   life or for a further reduction of the inductance 1.

As shown in Fig. 5, there is the possibility of reducing the low-frequency output voltage noise of the circuit arrangement by means of a circuit expansion.

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Due to the rapidly changing high switching currents and volt-
ages an interference voltage in the form of a low-frequency
noise voltage occurs, independently of and superimposed on the
desired modulation, at the output of an amplifier which is
connected for energy recovery reasons. This is the case, in
particular, if the high-frequency pulse sequence supplied to
the final stage by the controller includes a so-called jitter,
i.e. a statistically distributed jitter of the switching times
included therein.

The noise voltage which is undesirably superimposed on the
desired piezovoltage affects maintaining of a stable physical
position of the actuating element piezotranslator in the case
of being controlled by a fixed reference variable. However,
corresponding mechanical variations are superimposed on a
desired modulation as well.

It was already proposed to avoid the problem of high-noise
switched amplifiers by connecting an additional final stage
for fine control between said amplifiers and the load proper.
This final stage operates to the conventional, loss-inherent,
analog technology in the form of variable resistors and gener-
ates a relatively noise-free output signal. Due to the fact
that the downstream connected final stage with the coarsely
pre-controlled output voltage of the connected amplifier,
which for this purpose, can be adjusted higher by a fixed
small amount, only a negligible power loss will occur there.
Contrary to the more frequent ohmic loads which do not require
active discharging, said discharging must be included in suit-
able amplifiers for the inductive piezotranslators.

According to Fig. 6 it is known to use two completely switched
amplifiers 41 and 42 in the conventional manner (as in Fig. 3,
but without internal current control) in order to provide the
required positive and negative supply voltage in a correspond-

ing manner for the fine control of the downstream arranged analog final stage 43.

For this purpose, the assemblies 41 and 42 feed back their respective output voltages to the internal amplifier circuits 14 according to Fig. 3 and compare them with the reference variable of the physical position, but add a small fixed offset which offsets the amplifier 41 downwards by a small fixed amount and offsets the amplifier 42 upwards by the same amount.

The two capacitors 44 and 45, whose capacitances are low compared to the capacitance of the piezotranslator 2, provide the filtering of the switching frequency, which is required for the function of the connected amplifiers.

The downstream amplifier 43 with its own (not shown) control loop generates the correct output voltage at its output, again with only little noise, which is supplied to the piezotranslator 2.

The drawback of the above described circuit arrangement is that under control engineering conditions, it is possible to a limited extent only, to stably maintain a small difference of fixed magnitude between the two outputs of the amplifiers 41 and 42. This might be conceivable in the case of static mechanical reference variables and in the lower modulation range but is no longer possible in the range of a higher frequency modulation of approx. 2 kHz. The amplifier-specific and unavoidable phase shifts in the two amplifiers 41 and 42 hardly reach values of approx. 90° and a synchronisation in these two amplifiers can hardly be achieved.

Already a small phase difference between the amplifiers 41 and 42, however, is sufficient to exceed the desired small control

difference several times. Upon reaching the only insufficient-
ly suppressed points of resonance, at the latest, the synchro-
nisation problems become insurmountable. The principally known
solution of noise reduction can therefore not be employed in
5 the high frequency range of the modulation, which in fact is
the interesting one.

With a limitation to the lower frequency range, however, the
upstream energy-saving amplifiers 41 and 42 become rather
10 meaningless, because only low power values occur due to the
decreasing currents in the piezotranslator 2.

As shown in Fig. 5, according to another embodiment, only one
amplifier 41a is formed instead of the amplifiers 41 and 42,
15 which greatly reduces the overall expenditure.

The output voltage of this amplifier is still somewhat lower
than the output voltage which is expected at the piezotrans-
lator 2. By means of the additional provision of an internal
20 current control loop 13 (according to Fig. 3), when compared
to the amplifier 41, any points of resonance are effectively
suppressed in the amplifier 41a.

The downstream final stage 43 for fine control is adopted, as
25 is the capacitor 44.

The known upper amplifier 42 (Fig. 6) is replaced by an addi-
tional new voltage source 46. This is also connected with the
output of the amplifier 41a and includes an internally in-
30 stalled capacitor of adequate magnitude for blocking.

The magnitude of the direct voltage source 46 corresponds to
the previously controlled difference between the outputs 41
and 42, and is small compared to the maximum working voltage
35 which can be supplied to the piezotranslator 2. It corresponds

essentially to twice the peak value of the noise voltage occurring at the output of the amplifier 41.

The output of the dissipative amplifier 43 is controlled by means of a first control loop by feeding back the voltage of the piezotranslator 2, its charge integral, or a mechanical sensor 20 (similar to Fig. 3 or 4) to the correct, noise-free value which is amplified relative to the reference variable of the physical position.

The inner current control loop 13 is located in the controller of the amplifier 41a. For controlling the output voltage of the amplifier 41a, however, a separate voltage comparison is carried out independently of the amplifier 43, as this is pro-vided for in the state of the art. The sole parameter which is responsible for the controller 14 is the difference between the output voltages of the amplifiers 41a and 43, which is directly picked-off and supplied to the controller 14. Fur-thermore, the comparison is no longer made against the refer-ence variable of the physical position, but against a fixed reference voltage with a magnitude of half the source voltage.

Thus, the available supply voltage reserve for the amplifier 43 is no longer provided by the difference of the independent measurement of two parameters, which might easily be invalid-ated by phase errors, but is directly measured and controlled.

The advantage which results from the embodiment according to Fig. 5 lies in the following. The use of the fixed voltage source 46 allows the complete omission of a second switching amplifier 42 which is considerably more expensive. Thereby, the power losses occurring therein are avoided. By means of the resonance-suppressed current control in the amplifier 41a together with the directly controlled symmetry of the working voltage for the amplifier 43, the operation over the entire

previous frequency range of the amplifier 41a is possible
without any restriction.

All in all, the inventive circuit arrangement as well as the
proposed control concept allow the exact control of piezo-
translators as electrical actuating elements with a moderate
circuit expenditure, with an optimisation of the energy re-
covery being possible at the same time. By designing the con-
trol loop with or without an additional desired positioning
control, effects of undesired non-linearities of the piezo-
translator, such as the hysteresis effect and the long-term
drift, can be prevented.

List of Reference Numerals

1		Intermediate store
2		Piezotranslator
3,	4	Switches
5,	6	Recovery diodes
7,	8	Voltage sources UB/2
9		MOSFET
10		External blocking diode
11		Commutating diode
12		Current sensor
13		First controller
14		Second controller
15		Amplifier
16,	17, 22	Filters
18		Final stage
19		Third controller
20		Mechanical position sensor
21		Amplifier-filter combination
41,	42	Switched amplifiers
41a		Switched amplifier including current control
43		Analog amplifier in low-noise configuration
44,	45	Filter capacitors
46		DC voltage source